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ARI V(INT)2 Soldier Machine Interface Demonstrator: Results of Experimentation on SIMNET-D

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FOREWORD

The Systems Research Laboratory of the Army Research Institute (ARI) wants to help users and operators cope with the ever increasing complexity of the battlefield and the automated systems by which they acquire, transmit, process, disseminate, and utilize information. Increased system complexity increases demands on the machine users and operators. ARI's efforts in this area focus on human performance problems related to interactions with command and control centers and on issues of system design and development. Research covers such areas as user-oriented systems, information management and display, decision support, and the impact of "high technology" on systems integration and utilization.

One area of special research interest involves the soldier-machine interface (SMI). The aim of this research is to provide user-oriented functional specifications for a data-management display-systems architecture of a generic SMI--that is, an SMI adaptable to multiple battlefield functional areas such as command/control, maneuver, armor, cavalry, artillery, combined arms, etc. The initial development is focused on increasing the operational effectiveness of commanders of small units (i.e., combat units that exchange fire with the enemy).

Research in user-oriented systems is conducted as an in-house effort augmented through contracts with uniquely qualified organizations. The present experimental effort was conducted in collaboration with personnel from BBN Laboratories Incorporated with assistance from Perceptronics. The effort responds to requirements of Army Project 2Q263744A793, Human Performance Effectiveness and Simulation, and to special requirements of the U.S. Army Armor Center and School, Fort Knox, KY.

ARI V(INT)² SOLDIER-MACHINE INTERFACE DEMONSTRATOR: RESULTS
OF EXPERIMENTATION ON SIMNET-D

EXECUTIVE SUMMARY

Requirement:

The AirLand Battle concept will require small units (company and below) to fight a war in which agility, deception, and maneuverability are paramount to success. The battlefield information needed to fight this style of warfare will be produced by current and projected advances in sensor, communication, and data processing technologies. However, unless this information is tailored to the specific needs of the commander, the flood of data will overwhelm rather than aid him in making timely, effective decisions. The solution to this problem is to provide data management and display systems that will adapt the amount, format, and level of detail of information to: (1) the needs of commanders at various echelons, and (2) the changing needs of a commander as the tactical situation unfolds.

Procedure:

Expert system technology was used to develop a prototype information system as a real-time decision aid for tank platoon leaders. This prototype is labeled the ARI Vehicle Integrated Intelligence (V(INT)²) Soldier-Machine Interface (SMI) Demonstrator (VSD). In essence, the VSD is a software module consisting of a large number of mini-experts under the control of an "executive" expert. This knowledge-based decision aid was developed on a Symbolics 3670 superminicomputer in an object-oriented ZetaLisp environment. A color graphics system driven by the 3670 provided a tank platoon leader with the specific information needed to maneuver his unit undetected while executing an ambush of an enemy force. Ten experienced tank platoon leaders participated in experimentation on the SIMNET-D facility at Fort Knox. SIMNET-D provides a simulated tank compartment in which the crew may view scenes on their "vision block," displays that are comprised of computer-generated images that correspond to what is seen when they look out of the real buttoned-up vehicle. Tank crews may maneuver and exercise their skills and tactics on terrain constructed from a digital data base in ways that are similar to operations on a real battlefield. Performance in route planning and tactical maneuvering using the VSD was compared with performance using current paper map procedures.

Findings:

Performance with the VSD was consistently better with regard to such tactically significant factors as the time and accuracy in reaching a designated location, the available time to engage the enemy force, and the suitability of the "ambush" site selected. Other differences, while consistently in favor of the VSD, were not statistically significant.

Utilization of Findings:

The results of this experimentation provide an empirical demonstration that applied expert systems technology can be used to reduce the tremendous cognitive burden imposed on combat commanders in the data-rich, highly stressful battlefield environment. An independent evaluation of the VSD by personnel of the AirLand Battle Test Bed, DCD, USAARMS, Fort Knox recommended that "the development of knowledge-based systems such as V(INT)² should be continued." The expert modules devised during this project can serve as guideposts in the development of a simple, user-tested soldier-machine interface architecture adaptable to the needs of small unit commanders across a broad spectrum of combat operations.

ARI V(INT)² SOLDIER-MACHINE INTERFACE DEMONSTRATOR: RESULTS
OF EXPERIMENTATION ON SIMNET-D

CONTENTS

	Page
INTRODUCTION	1
Overview	1
Research Objective	1
General VSD Map Display and Manipulation Features	4
Overall Hardware Architecture	5
V(INT)2-SIMNET INTEGRATION	7
Background	7
Experimental Scenario and System Operation	8
Map Display and Manipulation Features of Current Prototype	9
General Planning Features	12
SIMNET EXPERIMENTATION	17
Prior Evaluation	17
VSD Installation in SIMNET	17
Experimental Design	18
EXPERIMENTAL RESULTS	21
Ambush Planning	21
Route March	23
Ambush Execution	24
General Discussion	25
REFERENCES	27

LIST OF TABLES

Table 1. Ambush site acceptance criteria	10
2. Terrain features available in VSD	11
3. VSD general planning features	14
4. VSD ambush planning features	15

CONTENTS (Continued)

	Page
Table 5. Median performance measures for ambush planning trials	21
6. Performance measures for route march trials . . .	24
7. Performance comparison for ambush execution . . .	24

LIST OF FIGURES

Figure 1. Illustration of VSD display as it appears after an ambush has been selected	6
2. The VSD display of an ambush plan, with the map magnified by use of the zoom mode	13

LIST OF ACRONYMS

Acronyms	29
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ARI V(INT)² SOLDIER MACHINE INTERFACE DEMONSTRATOR: RESULTS OF EXPERIMENTATION ON SIMNET-D

INTRODUCTION

Overview

In 1984 the Army Research Institute (ARI) initiated a project to develop and evaluate a prototype "intelligent" soldier-machine interface (SMI) for commanders of small combat units. The purpose of the project was to show some of the ways in which applied expert system technology can be used to reduce the tremendous cognitive burden imposed on combat commanders in the data-rich, highly stressful battlefield environment. The context selected to provide an early demonstration of some features of an 'expert' enhanced SMI is a tank platoon movement-to-contact in which an ambush of an enemy force is executed.

Research Objective

In the summer of 1981, the Army Science Board (ASB) made several recommendations regarding the application of microelectronics and other aspects of emerging technologies to improve the acquisition, processing, and distribution of battlefield information by commanders of small combat units (i.e., battalion and below). For example, in a letter to GEN Otis dated 10 September 1981 (Blanchard, 1981), GEN Blanchard described a concept for a display system "made possible by JTIDS and PLRS augmented by on-board sensors and microcomputer technology" that would "give the commander a detailed knowledge of where he and his friendly forces are, a display of both the enemy vehicles which he can see, and those behind the hill or camouflaged, which he cannot see. In addition, SINCGARS will provide the command and control essential to integrate and transmit the various displays and fused data to individual vehicles." This concept of an individual vehicle computer and display system produced by the ASB was named V(INT)² (integrated, intelligent Vetronics). The V(INT)² acronym was later redefined as Vehicle Integrated Intelligence.

In a related recommendation the ASB called for more research and development to improve the quality of the SMI to fully exploit the presumed benefits of emerging technologies. In furtherance of this goal, the Army Research Institute

(ARI) became a player in the V(INT)² arena via participation in the Armored Combat Technology Exploitation Concept Plan developed at TACOM in response to the ASB's recommendations. Among the functions to be provided by ARI were "up-front analysis of information and display requirements, crew interaction, soldier-machine interface issues, and other human factors pertinent to exploitation and testing of vetronics concepts and radically different vehicle configurations."

A follow-up meeting was convened by ODCSOPS at AMSAA headquarters, APG, on 5 November 1981. At the suggestion of ODCSOPS, CDEC was asked to conduct a series of experiments using what, at the time was described as, "current tactical display and positioning instrumentation to emulate some of the envisioned V(INT)² functions."

CDEC then embarked on a program to implement and test a V(INT)²-type display system. This involved the installation of a CRT aboard several tanks that provided a map display of the Hunter-Liggett terrain plus symbols showing the locations of blue and red tanks. Data collected incident to a full scale field exercise conducted in 1982 indicated that the presence of the display did not improve the "first shot" or the "kill" scores of the blue forces. In fact, performance often got worse (USACDEC, 1983). Many hypotheses were proffered to explain away these counter-intuitive results, but the upshot was that no further CDEC tests were conducted and the "quick reaction" V(INT)² program withered away.

In the meantime, ARI had embarked on a related long range R&D program that was focused on a loosely defined "next generation" armored vehicle. In an early effort to better define the V(INT)² system for this vehicle, Blasche and Lickteig (1984) described the functional and informational requirements of a V(INT)² system for small armor units: battalion, company, platoon, and crew. Their report details how each of these units might utilize V(INT)² to more effectively fight the battle. By depicting, in considerable detail, the potential impact of V(INT)² on small unit performance, the authors attempted to provide system supporters and designers with a better understanding of the Army's requirement for a vehicle-based automated command, control, and communication system.

To demonstrate the potential impact of V(INT)² on small unit performance, ARI began a research program to develop a prototype information management and display system employing expert system technology. The objective of this program was to provide a small unit commander (a tank platoon leader) with the battlefield information needed to plan and execute

local combat maneuvers. In 1984 a contractor team consisting of Perceptronics, Inc., BBN Laboratory, Inc., and Anacapa Sciences, Inc. was selected to provide additional technical expertise to this research program. Some of the guiding principles to the ARI approach were that:

- A microprocessor would be located aboard an individual vehicle and would provide information processed in real time or near-real time.
- Much of the information required for unit C² (detection, localization of OPFOR assets) would be downloaded from S2 elements at higher echelons (e.g., brigade).
- The system might conceivably be installed during a future M-1 PIP but most likely in a next generation vehicle.
- The sensor, communication, and information processing technology anticipated by the AirLand Battle (ALB) concept (e.g., BMS, VISTA, etc.) will be incorporated, with implementation in the 1995-2000 timeframe.
- The most serious SMI problem for the battlefield commander is information overload.
- Expert System and other artificial intelligence (AI) technologies are essential to overcome the information overload problem.

A key element of a successful data management and display system is a properly designed interface through which information is transferred between the commander and machine. The V(INT)² approach to developing such an interface was to create a research testbed to enable rapid prototyping of proof-of-concept demonstrations. The V(INT)² SMI Demonstrator (VSD) was designed to provide this rapid prototyping means for evaluating alternative approaches to the use of interactive input and output display screens, multi-function control panels, expert program-based decision aids, voice input of commands, synthetic voice alarms and instructions, and other candidate applications of "high-technology" to the SMI. The purpose of the expert programs was to take advantage of the high rate of acquisition, transmission, and processing of battlefield data available via "state-of-the-art" electronic technologies. Timely access to user-relevant information will provide a force multiplier to small unit commanders by allowing these

commanders to "disrupt the enemy's decision-loop" in the anticipated AirLand Battle and AirLand Battle 2000 environments.

By providing a dynamic graphic interface, the VSD enables measurement, in realistic man-in-the-loop tests, of the increase in operational effectiveness that can be expected from the innovative architecture, and data display and management concepts envisioned by the Army, DoD, and the scientific and industrial communities. Such research can provide objective data based on user performance, reaction, and acceptance that will enable systems designers and proponents to assess the potential improvements in operational effectiveness that could result from the incorporation of V(INT)² features in the SMI of future tactical systems. Initial V(INT)² efforts were focused on tank operations. However, the ultimate goal is to develop a simple, user-tested SMI architecture adaptable to the needs of small unit commanders across a broad spectrum of combat support elements, especially those to be supported by the Armored Family of Vehicles program.

General VSD Map Display and Manipulation Features

Figure 1 illustrates the commander's display that was developed for planning an ambush under this program. The software provides a series of expert programs that calculate expected routes, screen potential ambush sites for their acceptability and checks to eliminate any site for which the intervisibility is unacceptable between OPFOR and Friendly units as each traverses its expected routes. The display is shown at the point when the user has established an acceptable ambush site for the conditions selected. It shows the map derived from a digital data base of Fort Knox, KY. On the map the OPFOR position (diamond) and objective (circle) are displayed together with the position of the Friendly unit (square). The illustration shows the estimated route the system defines between the OPFOR position and objective and the estimated time to reach the objective. An ambush site that meets the site criteria is displayed and the recommended route for the Friendly Unit to reach it is shown. Figure 1 is reproduced at about half of the size of the actual display, which was highly legible. See Figure 2 for a magnified, more readable, view of the geographic details of the ambush.

Surrounding the map are the menus that are accessed by a computer mouse, a small hand-held device that is rolled over a smooth surface to move the cursor around the display. To the right of the map the initiating assumptions concerning the OPFOR position, speed and objective and the Friendly position are first established by the user. Then the user defines the constraints he wishes to impose on acceptable ambush sites, in terms of lead time to reach the site before the enemy comes into view and the engagement window, i.e., the time during which the enemy unit will be exposed to fire. Below the constraints are the functions that can be selected at this point in the ambush planning activity. Initially, before any site has been examined, the user selects the menu item "Plan Ambush" and the display shown in Figure 1 results.. The area directly south of the map shows the numerical characteristics of the ambush site that has been selected by the system. As planning proceeds, the menus change interactively to provide the full functionality of the system. Later sections of this report for a full description and explanation of this functionality.

In summary, the VSD incorporates features designed to enable small units to fight a style of future combat in which agility, deception, and maneuver are paramount to success. V(INT)² will help the company commander and tank platoon leader cope with the information glut of the future battlefield. It will provide processed information in timely fashion and in context with the situation and user needs. The expert programs embedded within the V(INT)² system will serve a two-fold function: (1) to be trusted, knowledgeable advisors to the tactical planner and executor, and (2) to relieve the planner and executor from various deterministic decision-making functions.

Overall Hardware Architecture

The VSD was developed on a Symbolics 3670 superminicomputer, in an object-oriented zeta Lisp environment. Interaction with the tank commander was through a Symbolics color graphics system and a mouse-selected menu and graphics pointing system. Interaction with the experimenter and programmer was supported through the mouse and keyboard on a black and white CRT.

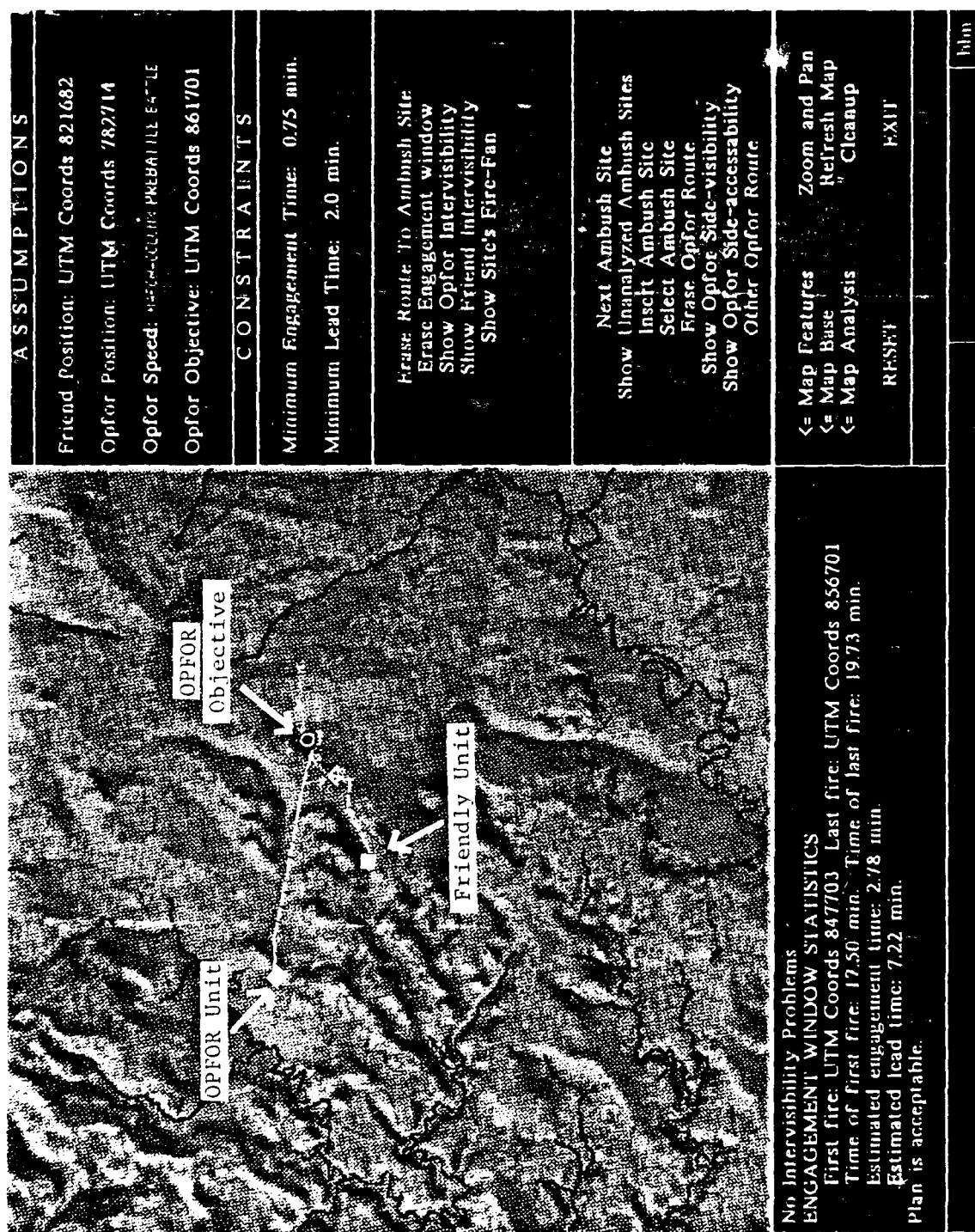


Figure 1: Illustration of VSD display as it appears after an ambush has been selected.

V(INT)2-SIMNET INTEGRATION

Background

By mid-1986, two expert-system software modules had been developed by the original VSD contractor team. The first module provided expert-system assistance to a tank platoon leader in planning and executing a Movement-to-Intercept (Ambush) operation. The second module provided assistance in setting up a company-level Hasty Defence operation. In order to obtain an early assessment of the value of the V(INT)² concept, it was decided to arrange for a test of the prototype ambush module in a more realistic setting. The DARPA-sponsored SIMNET facility at Fort Knox appeared to provide a suitable medium for a more realistic test. Accordingly, in March 1986 ARI and DARPA signed a Memorandum of Agreement whereby the ARI arranged to have the ambush module software of the VSD installed and tested at the SIMNET Development Center (SIMNET-D) at Fort Knox, KY. BBN Systems and Technologies Corporation provided the technical lead for this effort.

There are two SIMNET facilities at Fort Knox. SIMNET-D is used for evaluation of advanced doctrine and combat development systems. It provides a number of simulated tank compartments in which crews may view scenes through their computer-graphic vision blocks that correspond to what is seen by each crew member when he looks out of the real buttoned-up vehicle. Tank crews may maneuver and exercise their skills and tactics on terrain constructed from a digital map data base in ways that are similar to operations on a real battlefield. Individual tanks may participate in simulated battles because they are connected via a computer network to other similarly-equipped vehicle simulators. SIMNET-D has reconfigurable crew spaces, making it possible to emulate novel combat development systems and has data recording and analysis tools for collecting and analyzing experimentally derived data. In the training version of SIMNET, SIMNET-T, up to 200 of the individual simulators and a central control center provide realistic day-to-day tactical training for larger armored units. At the time this experiment was conducted, SIMNET-D was not yet complete and the experiment was actually run on a tank from the SIMNET-T array, modified so that the measurement systems of SIMNET-D were available.

This report will first describe the functionality of the VSD in its current configuration, the version used for the SIMNET evaluations. It will then describe the methodology and results of the test and present recommendations for

further development of the V(INT)² concept based on this experience with the VSD.

Experimental Scenario and System Operation

The tactical scenario used for the SIMNET experimentation is one in which a tank platoon conducts an intercept to ambush mission. The scenario setting is well in the future and embodies the fighting concepts envisioned in AirLand Battle, Army 21 and beyond. For example, it is assumed that in the future, the Armor School would include V(INT)² training as part of its curriculum; the system would therefore be a well-understood and accepted on-board decision-aid. New sensors and communication means would provide information and intelligence directly to V(INT)²-equipped units. Information is parsed in a manner such that directly useable data is received or sent to the unit. As an example, on today's battlefield moving target indications (MTI) are transmitted in mass and often include all MTI detected across a division or even a corps front. An analyst must sort out those MTI of interest to his situation and this process may require over an hour of an individual's time. V(INT)² would identify those MTI of interest, based upon the system's knowledge of the situation and task organization, and provide "tailored" information to a user.

The demonstration at Fort Knox was run on a SymbolicsTM 3670 computer with one monochrome and one color monitor, a 167 Mb disk drive and 2Mb random access memory. Although other functionality was originally developed, the version of the software prototype utilized was only capable of conducting route marches and recommending ambush sites along an enemy route of advance, given an enemy location, a Friendly location, visibility, enemy rate of movement, and an enemy objective. It retained all the expert programs required to implement these capabilities.

In suggesting possible ambush sites, the VSD considers the enemy's likely route of advance and rate of movement, generates a list of possible ambush sites, and then compares each site against a set of criteria. Each site is classified as "acceptable" if it meets all the criteria, and "unacceptable" otherwise. In considering a particular site, the VSD generates a route from the friendly position to the site, and checks to determine that the site can be reached with sufficient lead time, and that it offers an adequate engagement window. Then intervisibility between Friendly and OPFOR tanks is checked at each corresponding point in time

along their respective routes. The site is also checked against various other criteria, as indicated in Table 1. These criteria were developed in discussions with subject matter experts from the U.S. Army Armor School, Fort Knox, KY.

The system will return the results to the user that it obtains as it checks each of the operator-set parameters (see bottom left panel of Figure 1). The user is able to "scroll" through this information to review the data pertaining to each site. The user may "insert" an ambush site in a location not considered among the candidate ambush sites suggested by the system. The VSD will then perform the analysis on the inserted site in the same manner as described previously. This allows the user to have a site analyzed that he considers more favorable than any of the sites suggested by the VSD.

Map Display and Manipulation Features of Current Prototype

The VSD commander's display presents a color map derived from a digital map data base and a series of menus that provide access to the various functions that are available to the commander. The system was originally developed using a map of the Fulda Gap, Germany, based on Defense Mapping Agency (DMA) ARTBASS Level 2 data, with elevation data points on a 25 meter grid. However, the demonstration experiment involved executing ambushes on the SIMNET terrain, and therefore required the use of a map corresponding to the terrain database that had been developed for SIMNET by BBN Delta Graphics Inc. This map used DMA elevation data of the Fort Knox, KY area on a 125 meter grid, but terrain features, such as tree lines and building locations were placed arbitrarily, rather than representing true locations. A map pixel in the VSD display represented a square 62.5 meters on a side. The data bases and control programs make it possible to present the underlying terrain in several presentation modes together with several overlays of terrain features.

Table 1
Ambush Site Acceptance Criteria

Restrict Visibility Enroute. For each site, the program takes the speed of the two units into account and conducts a fast-time simulation of the units' advances to their respective objectives to determine if, at any point on the respective routes, one unit will be visible to the other. If the answer is positive for more than 5% of the shorter of the two transit times, then the site is rejected.

Minimum Engagement Window. Sites are screened to determine the time during which the OPFOR will be visible to the Friendly for attack after arrival at the given site. The size of the window is a variable that can be set. For the Fort Knox test it was set to 2.0 minutes.

Minimum Lead Time. Sites are screened to determine if the Friendly Unit will arrive at the ambush site a given amount of time prior to the time the OPFOR first comes into view. Lead Time is a variable that can be set. For the Fort Knox test it was set to 2.0 minutes.

Minimum Distance to a Forested Area. Sites are screened to determine if they have adequate cover; that is, the Friendly Unit could position itself near the cover of a forest. The minimum distance is a variable that can be set. Since the Fort Knox data base does not include forested areas in its definition, this variable was not used as a criterion.

Not Near Building. Sites near a building were considered not suitable for an ambush. On the Fort Knox data base, sites closer than 100 meters to a building were rejected.

Not Near River. Sites near a river were considered not suitable for an ambush. For the tests, sites closer than 100 meters to a river were rejected.

Route to Site does not Require Crossing OPFOR Route. Since OPFOR speed is not completely predictable, it was considered bad tactics to allow a Friendly route to cross the predicted OPFOR route. Sites that required it were rejected.

The base map may be presented on the VSD display in shades of grey, dark grey or tan. Similarly, elevation information may be presented by color shades or, by the use of selective slope shading to create the perception of hills and mountains artificially. This slope shading is illustrated in Figure 1. Three levels of exaggeration of the relief features are available, with the smallest one corresponding to what the terrain would look like from a significant altitude. The two maps, Fulda Gap and Fort Knox, do not have the same terrain detail available for construction of overlays. Table 2 provides a description of what is accessible through overlays from the commander's display for each map.

Table 2
Terrain Features Available In VSD
(Available Features Indicated by X)

<u>Features</u>	<u>Fulda Gap</u>	<u>Fort Knox</u>
Elevation Contours	X	X
Forested Areas	X	0
Tree Lines	0	X
Rivers	X	X
River Fords	X	X
Bridges	X	X
Buildings	0	0
Towns	X	0
Primary Roads	X	X
Secondary Roads	X	0
Railroads	X	0

An additional feature is the ability to shade selectively areas of the map having specified terrain properties. For example, it is possible to use the mouse to point to a specific coordinate on the map and then to request that all areas of the terrain that are at a higher (or lower or equal)

elevation to the specified point be calculated and displayed in a new shade. Similarly, areas with steeper or shallower slope or faster or slower average travel speed may be displayed. These features were not introduced to the test subjects in the experiment and therefore are not described in detail.

Finally, the system permits the user to zoom in on a particular area of the map to obtain successively more detailed views and zoom out again. Figure 2 shows the same ambush plan as Figure 1 under 2:1 magnification. In this view the OPFOR Route, ambush site and friendly route are clearly shown. The estimated time for the OPFOR tank to reach his objective is indicated (21.89 min), as is the time for the Friendly tank to reach ambush site 33 (10.28 min). The lines drawn from the ambush site to the OPFOR route indicate the portion of the route for which the OPFOR tank will be exposed to fire. The triangle directly above the OPFOR route shows the current, operator controlled, mouse cursor position. At all times it indicates the elevation of the point at which it is pointing (213 m) and the UTM coordinates of that point (820731). When zoomed in, movement of the mouse around the display causes the area of the magnified map to shift (the pan feature) so that any part of the entire map area may be shown. A limitation of the current implementation is that the zoom and pan features are implemented directly using the hardware zoom capability of the Symbolics computer. Therefore only the map portion of the display is visible in the zoom mode and the menus are unavailable until returning to the unzoomed state. A preferred implementation would use a software program to zoom only the map and leave the menus accessible.

General Planning Features

The system incorporates a number of planning features that are potentially useful to the tank commander in a variety of offensive and defensive tactical modes. Table 3 describes the general planning features accessible in the current implementation. The first four are concerned with establishing the position and context of the OPFOR and Friendly forces. It is assumed that on the battlefield of the future, this information would be provided to the commander by electronic data communications.

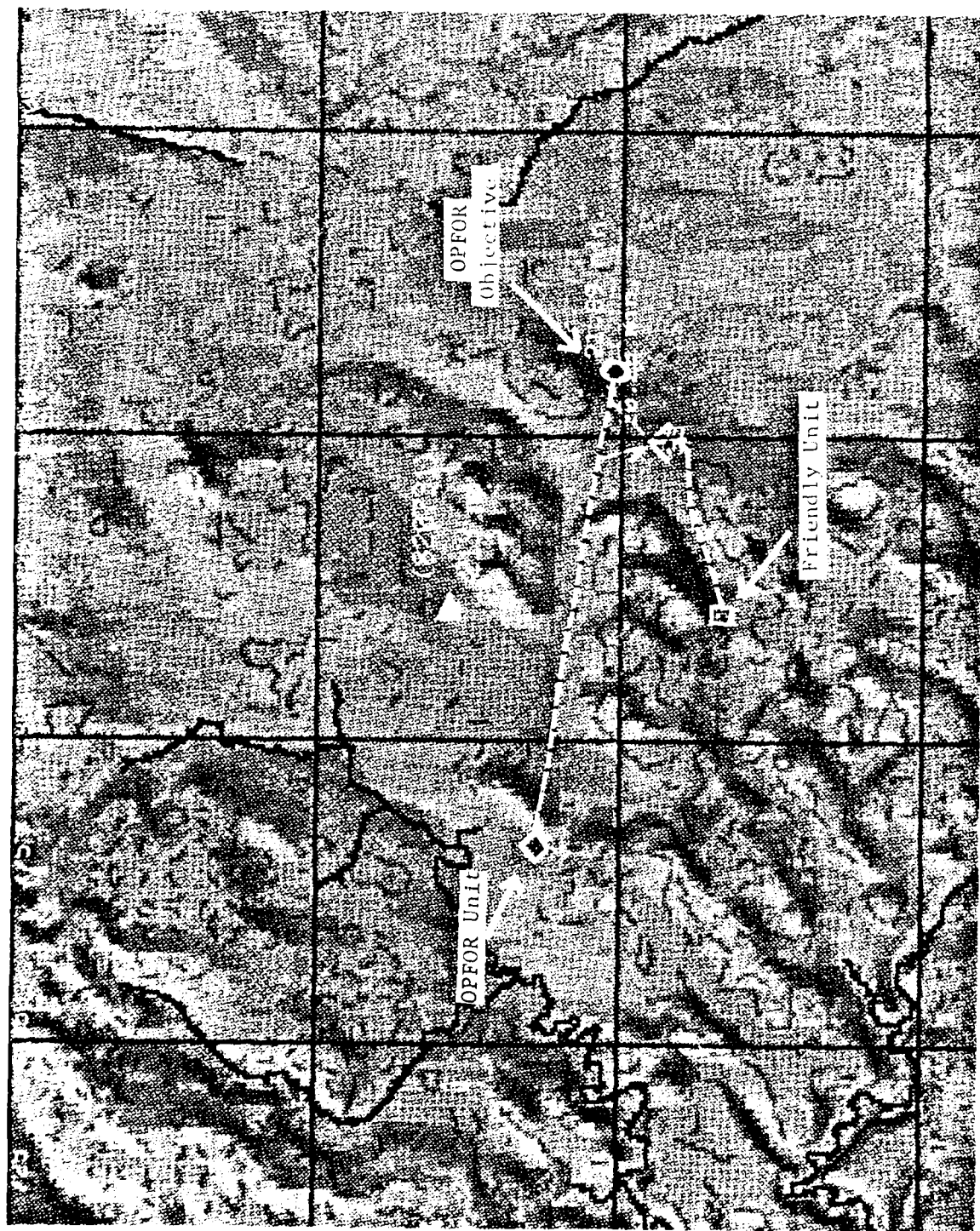


Figure 2: The VSD display of an ambush plan, with the map magnified by use of the zoom mode.

Table 3
VSD General Planning Features

Select OPFOR or Friendly Position. Positioning the mouse at the desired location and clicking indicates the OPFOR or Friendly placement.

Select OPFOR Objective. Positioning the mouse and clicking indicates the placement of the OPFOR objective.

Set OPFOR or Friendly Speed. For purposes of travel time and enroute intervisibility calculation, allows the user to select the assumption to be made about travel speed. Maximum, normal and slow speeds are selectable.

Plan OPFOR or Friendly Route. Selecting this menu item draws a route on the map automatically. The OPFOR route is drawn from the present position to the assumed objective. The Friendly route is drawn from the present position to an indicated destination. In the current version the only destination is an ambush site. The route selected avoids obstacles and slopes steeper than 15%; it crosses rivers at bridges or fords. In this prototype it ignores the availability of roads.

Calculate Intervisibility. From any point on the map defined by a mouse click, the system will calculate and display all points that are seen by and can see the given point on radii throughout the map.

Show or Erase Fire Fan. Using the same algorithm as the intervisibility calculation, it shows the areas of direct fire coverage from a defined point out to the range of the tank's main gun, currently set to 3500 meters.

The one maneuver that the prototype was specifically designed to implement was the ambush. Accordingly, there are some specific commands in the menu that build on the general purpose commands, but that are designed specifically to assist in carrying out an ambush. In a full implementation of the concept there would be special purpose commands for a variety of offensive and defensive maneuver planning activities. The features associated with ambush planning are shown in Table 4.

Table 4
VSD Ambush Planning Features

Plan Ambush. When the OPFOR position, speed, and objective together with the Friendly position and speed are defined, this command carries out all the functions required to complete the specification of an ambush plan. These functions include OPFOR route definition and evaluation of potential ambush sites. The process terminates when the first acceptable site is found and a route from the Friendly position to the site is specified for the user.

Select Ambush Site. The system automatically generates a large number of candidate ambush sites for screening as indicated below. Potential sites are located by following a perpendicular from the OPFOR route until visibility of the route is just lost. Each such position relatively near the Friendly position is defined as a candidate site. Positioning the mouse on such a site and clicking selects that site for evaluation or, if already evaluated as acceptable, designates it as the site of choice.

Move Ambush Site. Positioning the mouse and clicking on a candidate site allows the user to move it to any new location.

Insert Ambush Site. Allows the user to mouse-click on any map position and identify the position as a new candidate ambush site for subsequent evaluation.

Show or Erase Ambush Sites. Displays all candidate sites. For those that are already evaluated, indicates by color coding whether or not they were found to be acceptable.

When a candidate site is selected for evaluation, either by the automatic process or manually, it is subjected sequentially to the series of pass-fail criteria enumerated in Table 1. If the site fails any criterion, the evaluation is terminated at that point and the site is designated as unacceptable. A record is kept of the criterion that it failed. If it passes all criteria, a route from the Friendly position to that site is shown and the site is designated as acceptable.

It should be pointed out that these criteria were selected to be feasible, practical and useful for the Fort Knox data base. In earlier versions using the Fulda Gap data base, proximity to towns and forests was considered. It is, in fact, not difficult to impose any criterion that can be specified in algorithmic form.

SIMNET EXPERIMENTATION

Prior Evaluation

The VSD concept has been evaluated in published reports twice previously. In Harris and Geiwitz (1985) the Fulda Gap version was evaluated using Army Reserve officers who used the system to plan ambushes. The performance using a V(INT)²-type display was compared to that using paper maps for planning. When the paper plans were submitted to the V(INT)² system for evaluation, it was found that the paper map planning produced more exposures to the enemy and that they were of longer average duration. Paper map planners also produced ambush plans that had a significantly lower chance of mission success than those produced using the V(INT)²-type system.

In McGee and Lynd (1987) Army Air-Land Battle Testbed personnel conducted a static evaluation of the potential usefulness of an earlier version of the VSD features for use by platoon leaders, company commanders, and battalion commanders. These authors also provided a useful critique of specific design features from the perspective of an Army user.

VSD Installation in SIMNET

In the SIMNET evaluation to be described here, the evaluation criteria were intended to include interaction between real tank operations and the use of the VSD display. In order to accomplish this objective the VSD display was installed in a SIMNET tank module in a position that was accessible to the tank (platoon) commander and connected directly to a SIMNET Tank simulator so that the current position of that tank could be displayed as a tank icon on the VSD display. When the tank simulator executed a maneuver, the results of the maneuver were shown on the VSD display, updated every five seconds. Thus, in addition to the planning features, the display was useful for navigation over the terrain, following either a predefined route, or one planned by the VSD software. Accordingly, the system was evaluated by comparing the performance of experienced tank platoon leaders (1) using the VSD system versus (2) using a paper map, (as they would today), while they executed route marches and planned and executed ambushes. Since the map was effectively a printout of the simulator's terrain data base, it corresponded closely to what was seen on the display.

In order to install the VSD Symbolics Display in a SIMNET tank, the loader's position was modified and the display installed where the loader would normally be positioned. The display was set up at waist height, tilted about 45° upward and directly facing the commander. In order to view it, the commander looked slightly downward and to his left. It was positioned approximately 30 in from his typical eye position. The Symbolics display software required interaction using a computer mouse. A small smooth board was attached to the Commander's left leg, with velcro, like a clipboard might be, and this board was the surface on which the mouse was manipulated by his left hand.

Experimental Design

After one day of pilot runs and shake down of the system, the evaluation took place over a four-day period. Each half-day one crew, consisting of a tank commander and a driver, completed the three phases of the test, lasting a total of approximately four hours. Thus, eight crews participated in the formal tests. The commanders were officers who were qualified as tank platoon leaders, and the drivers were enlisted men qualified as tank drivers. The crews had not had prior experience working together. Personnel were drawn from training units stationed at Fort Knox.

First, the crews were introduced to the system and to the SIMNET simulators. They received no specific training using the tank simulators. It was assumed that their live tank experience would transfer to the simulated conditions. They spent about one-half hour using a standard protocol to learn to use the VSD planning system. Then, in sequence, using either paper maps or VSD they planned four ambushes (Phase 1); executed two predefined route marches (Phase 2); and planned and executed four ambushes (Phase 3).

In Phase 1 they were required to plan four ambushes; two with paper maps (M) and two with the VSD (V), each from a different initial position and OPFOR position and objective. The order of presentation was MVVM. This planning took place outside the tank, either in front of the VSD display or at a table presenting the paper map. Four scenarios were used in a counter-balanced order so that no crew saw the same scenario twice. In all cases, when the VSD system was being used, no constraints were imposed on the commander concerning either the specific VSD features to use or the order in which to use them. These decisions were left up to the individual participants.

In Phase 2, they then executed two predefined route marches, each having three way points and a destination. Each march, when executed accurately, was approximately 6 km long, and took about 20 min to execute, driving at normal speed. By execute, we mean that a tank commander and driver actually entered the tank simulator and drove the prescribed route. In the paper map condition, the VSD display was disabled and the crew used the paper maps to navigate the route. In the VSD condition, the display was turned on and the commander could see the tank icon moving across his screen as he instructed the driver to move out. The driver had no display, but, as is usual, relied on the commander for instructions about how to proceed. Again there were two different route march scenarios, so that no crew executed the same march twice.

Finally, in Phase 3, the crews planned and executed four ambushes. Once inside the tank, they were given the OPFOR position and assumed objective and their own position. They were then required to plan an ambush and to actually drive to the selected ambush site and wait for the enemy tank to come into view. In this case also there were four different scenario situations presented. The crew solved two of them with paper maps and two using the VSD system. The order of presentation of map (M) and VSD (V) conditions was the same for all crews (MVVM), but the order in which the scenarios were presented was counterbalanced across crews.

Data were collected in five ways. First, individual trials were observed and timed using a stop watch. This was the primary method for obtaining performance time data using paper maps. Second, the Symbolics machine was programmed to record a trace of the sequence of actions taken by each commander as he interacted with the VSD system. This made it possible to reconstruct a trial from the point of view of system utilization and provided both timing and accuracy data related to system use. Third, for all paper map ambush trials, the ambush sites selected by the crews were later entered into the VSD system and evaluated to determine if they were acceptable sites according to the criteria set by the system. Fourth, the SIMNET facility has provision for recording a trace of the time history of every observable action each tank takes on the battlefield. For the route march and ambush execution trials these data were available concerning actual paths traversed. Fifth and finally, after completion of the four hours of testing, the crews were debriefed using a standard interview protocol and their comments were made a part of the record.

EXPERIMENTAL RESULTS

Ambush Planning

The initial ambush planning trials were designed mainly to provide additional training and familiarity with the VSD system. However, they were administered in a way that made them comparable to those in the study undertaken by Harris and Geiwitz (1986). The only change was that the VSD functions had been revised and the crews were operating on the Fort Knox data base rather than Fulda Gap. The initial planning trials from Phase 1 were pooled with the planning phase of the plan-and-execute-trials of Phase 3 of the study in order to have a larger sample size. Although slightly different measures were taken to those of Harris and Geiwitz (1986), the results were very similar. The results are shown in Table 5.

Table 5
Median Performance Measures for Ambush Planning Trials

<u>Measure</u>	<u>VSD</u>	<u>Paper Map</u>	<u>Significance</u>
Lead Time	433 sec	0 sec	p < 0.0004
Engagement Time	233 sec	0 sec	P < 0.00005
Planning Time	157 sec	140 sec	Not Signlf.
Range at First View	1413 m	1237 m	Not Signlf.
Minimum Range	884 m	757 m	Not Signlf.

With the VSD, 100% of the planned ambushes produced sites that were judged acceptable by the criteria listed in Table 1, while only 14 out of 31 (45%) of the paper ambushes were judged acceptable ($P < 0.0001$). Since the crews had had little familiarity with the operation of SIMNET and with a somewhat unorthodox "ambush" maneuver, the performance measures favor the VSD trials. Nevertheless, the results are indicative of the difficulty of planning ambushes with paper maps. It is just too difficult to envision, in a short amount of time, whether or not a route will allow intervisibility between the Friendly unit and the OPFOR and the extent to which the OPFOR will be visible from a site selected for an ambush. This is among the reasons why "ambush" operations are not currently a part of U.S. Army doctrine.

The magnitudes of lead time and engagement time were calculated by the VSD program for all sites. Because of the way that the VSD rule system worked, if a site was found unacceptable because its lead time was too short, then its engagement window was undefined, and conversely if the engagement window was too short, then its lead time was undefined. These undefined lead times and engagement times were set to zero. In order not to weight these zero times inappropriately, medians instead of means were calculated (see Table 5). The median lead time when the VSD was used was 433 sec while it was 0 sec for paper map trials ($P < 0.001$), and the median engagement time was 233 sec for the VSD trials while it was 0 sec for the paper trials ($P < 0.0001$). An alternative way of treating the undefined data is to discard them instead of setting them to zero. In this case, the median lead time for the 17 paper-map sites with specified lead-times was 400 sec which is not significantly different from the 433 sec median lead time for the VSD sites. However, the median engagement time for the 26 paper-map sites with specified engagement windows was 83.5 sec, and this is significantly shorter than the 233 sec median for the VSD sites ($P < 0.001$). There were no significant differences in planning time, range at first view, or the minimum range that was achieved by the ambushes planned in the two cases.

A significant difficulty with the current VSD system was the resolution of the plan-view display. At the minimum magnification each pixel on the display represented approximately 65 meters square. This resolution was an artifact of the way in which the Delta Graphics data base represents the terrain. It uses polygons of varying size, depending on the detail portrayed. Pixel size was selected so that the minimum magnification map would provide sensible terrain interpretation. Furthermore, the tank icon was a square, four pixels on a side and therefore the position of the tank icon could only be set to an accuracy of ± 250 meters. Since the system retained the tank position coordinates accurately and the SIMNET tank was represented on the terrain to an accuracy corresponding to the size of the tank, about 20 meters, there was a significant discrepancy between the two representations. This was unavoidable, given the test situation, but produced significant positioning errors of which the test crews were not aware. For this reason, when evaluating the paper map trials, the acceptability of the ambush site was based on any of the four pixels surrounding the location of the Friendly tank. Other performance measures that would be insensitive to these errors were chosen where possible. Our experience suggests that in an operational version of the system it is essential

that the terrain data base have a resolution of better than 25 meters so that the users may have confidence that their indicated and actual positions are in accurate registration. A navigation sensor must also have sufficient resolution so that it does not further degrade the accuracy of position identification.

Route March

The route march trials were designed to assess the degree of navigational assistance to the commander that is provided by the VSD plan-view display of the geographic area together with a dynamically changing indication of the position and orientation of his own tank. As shown in Table 6, the median destination accuracy was overwhelmingly in favor of the display. In order to be sure that this result was not caused by a single trial using paper maps during which the crew was hopelessly lost, and because of the limited resolution of the tank position display, we also calculated the number of trials in which the final position of the tank was within 300m of the intended route march destination. Again, as shown in Table 6, the results strongly favored use of the VSD plan-view display. In fairness to the crews, it should be pointed out that, while the SIMNET Fort Knox map is a faithful representation of the terrain that is viewed from the tank vision blocks, it lacked the rich presentation of distinctive landmarks that are typically available on military area maps. On the paper map trials, for bearing information, the crews had to rely mainly on terrain shape, rivers and the location of tree lines. However, we do not believe that the large differences can be attributed solely to this effect. There is little doubt that the navigation aid greatly improved route-march performance.

With respect to the time to reach the destination, the paper map group took longer, as indicated in Table 6. There was also a large, but statistically insignificant increase in variability of travel time for the paper map group. Their times ranged from 12 to 40 min. The latter march was cut off by the experimenter when the crew appeared hopelessly lost. For the VSD trials the range was from 9 to 19 min.

Table 6
Performance Measures for Route March Trials

<u>Measure</u>	<u>VSD</u>	<u>Paper Map</u>	<u>Significance</u>
Median Destination Accuracy	230 m	2160 m	p < 0.05
No. Terminating within 300 m of Destination	8 of 8	1 of 8	p < 0.0014
Median Time to Destination	16.6 min	20.0 min	Not Signif

Ambush Execution

In the last phase of the experiment each crew first planned and then drove the four ambush routes. Since the crew did not include a gunner, the measure of success of the ambush was the number of cases in which the OPFOR tank was sighted and could have been fired upon. When the crews traversed the route to the site, they did not always arrive exactly at the planned destination. A second measure was therefore the distance between the planned site and the actual location at which the crews positioned themselves. Table 7 shows the results comparing performance with the VSD to that with the paper map. For both these measures the results favored the VSD condition, but were not significant statistically. Since this phase was primarily a navigation task, we expected large effects similar to the results obtained with the route-march condition. However, in order to keep the trial length short enough to undertake a meaningful number of trials, the friendly forces were positioned so that they were only about 3 km from the nearest acceptable ambush site. As a result, the VSD navigation aid proved not to be as critical to good performance as might have been expected.

Table 7
Performance Comparison for Ambush Execution

<u>Measure</u>	<u>VSD</u>	<u>Paper Map</u>	<u>Significance</u>
No. OPFOR sightings	9 of 14	7 of 16	Not Signif.
Distance between Planned/Actual Sites	429 m	654 m	Not Signif.

General Discussion

While each tank commander had specific comments, they were, in general, uniformly positive about their experience with the VSD display. The most desired feature of the display was the land navigation capability that it provided for the experiment. It was also observed that the ambush maneuver is very difficult, if not impossible to undertake today using paper maps. It is just too hard to undertake the intervisibility calculations required to assure that the tank will not be seen by the OPFOR while enroute to the ambush site. Our ambush scenarios were too short to bring out the full implications of this difficulty. The paper map group tended to identify sites close to those that were picked by the VSD analysis and intervisibility was not as serious an issue as it usually would be.

It was expected that the crews would have considerable difficulty learning to use the mouse and the screen-based menus that were provided. This did not turn out to be the case. The familiarization time and practice during the ambush planning trials seemed to provide sufficient experience so that the crews were not limited in what they could accomplish with the display despite their lack of familiarity with it.

This was one of the first experiments to use the SIMNET facility for system evaluation and sufficient attention was given to training in the use of the SIMNET tanks. Subsequent studies have shown that subjects should have as much as 4-8 hours of familiarization before undertaking experimental studies. The subjects in this study were given only a five-minute orientation to the SIMNET tank and only two of the crews had previous SIMNET experience. This probably contributed to the poor performance of the paper map navigation trials.

Perhaps the most interesting observations concerned the interactions between the commander and the tank driver when using the VSD display. The commanders reported that they spent a great deal more time than usual guiding the driver and that this extra workload interfered with the more important task of surveillance for enemy threats. Because the display gave them such detailed information about their position relative to the desired route, they tended to continually correct the driver, rather than giving him a general objective and leaving the driving to him. This required the commander frequently to look down at his display rather than out the vision blocks. This problem would be immediately alleviated by providing the driver with his own display. While the driver's display could be one that only instructs him about what to do to stay on course, we

recommend that he be provided with his own plan view display that is wide enough to provide the terrain context in which he is to navigate in order to follow the recommended route.

It was observed both by the crews and the experimenters that the VSD screen was too cluttered with features that appeared to be of little use. This was because the VSD system was designed for a much wider range of capabilities than could be tested, given the resources available. Before a system like this one is deployed, there should be extensive observation of how it is used in a variety of types of scenarios. Then a small number of the most desirable features can be selected by the user and the clutter resulting from such a rich menu of alternatives can be reduced.

Finally, although the mouse that was moved on the pad attached to the commander's knee was utilized satisfactorily for the test, it is recommended that in an operational application it be replaced by a touch sensitive display which can accommodate a pointer-driven interface almost as well as the mouse.

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List of Acronyms

ALB	AirLand Battle
AMSAA	U.S. Army Material System Analysis Activity APG, MD
APG	Aberdeen Proving Ground, MD
ASB	Army Science Board
BMS	Battlefield Management System
C2	Command and Control
CDEC	Combat Developments Experimentation Command, Ft. Ord, CA
DARPA	Defense Advanced Projects Agency
DCSOPS	Deputy Chief of Staff for Operations
JTIDS	Joint Information Distribution System
M-1	M-1 Abrams Tank
OPFOR	Opposing Force
PIP	Product Improvement Program
PLRS	Position Location Reporting System
RPV	Remotely Piloted Vehicle
S2	Brigade or lower intelligence staff
SIMNET-D	Simulated Network - Developmental
SINGARS	Single Channel Ground and Airborne Subsystem
SMI	Soldier-Machine Interface
TACOM	U.S. Army Tank and Automotive Command
VISTA	Very Intelligent Surveillance and Target Acquisition
V(INT) ²	Vehicle Integrated Intelligence
VSD	V(INT) ² SMI Demonstrator